



An Introduction to Variable-Resolution Modeling

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Presentation

- *Definitions and Basic Concepts*
- *Importance of Variable Resolution Modeling*
- *Example*
 - Cross Resolution Model
 - Integrated Variable Resolution Model
- *Challenges of Variable Resolution Modeling*



Definitions and Basic Concepts

Definitions and Basic Concepts

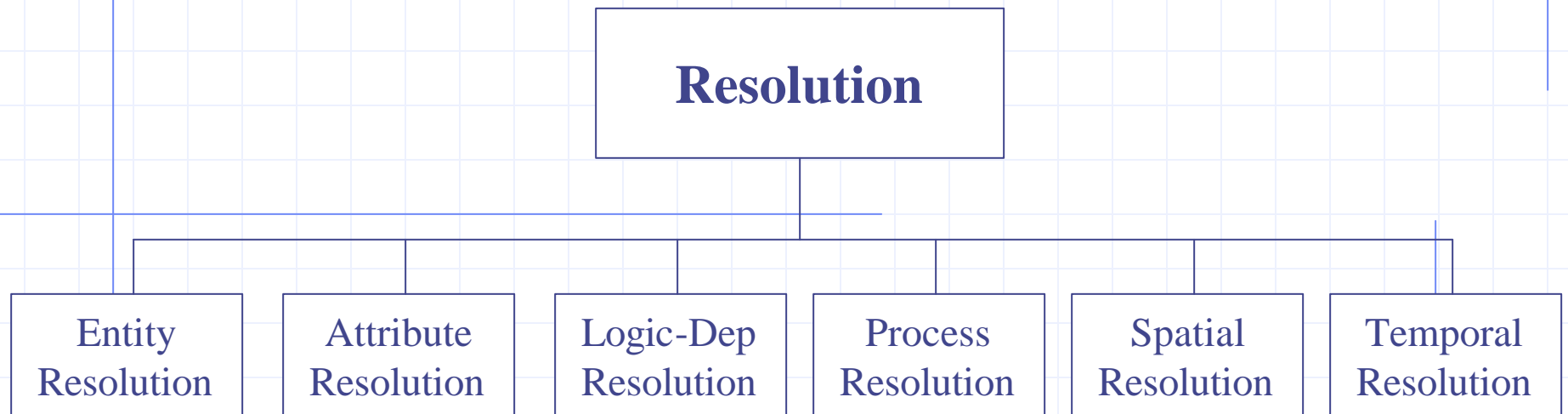
➤ **Variable Resolution Model:**

Models which allow the user to readily change the resolution or level of detail at which phenomena are treated.

➤ **Two ways to accomplish:**

- Cross Resolution Model: Linking existing models of differing resolution.
- Seamless Design: Design which permits changing of resolution with consistency of representation and prediction.

Definitions and Basic Concepts



Relative Resolution Between Models Quickly Becomes Ambiguous...

Definitions and Basic Concepts

➤ **Consistency:**

Defined by Websters:

In agreement or harmony...compatible...holding the same principals or practice...

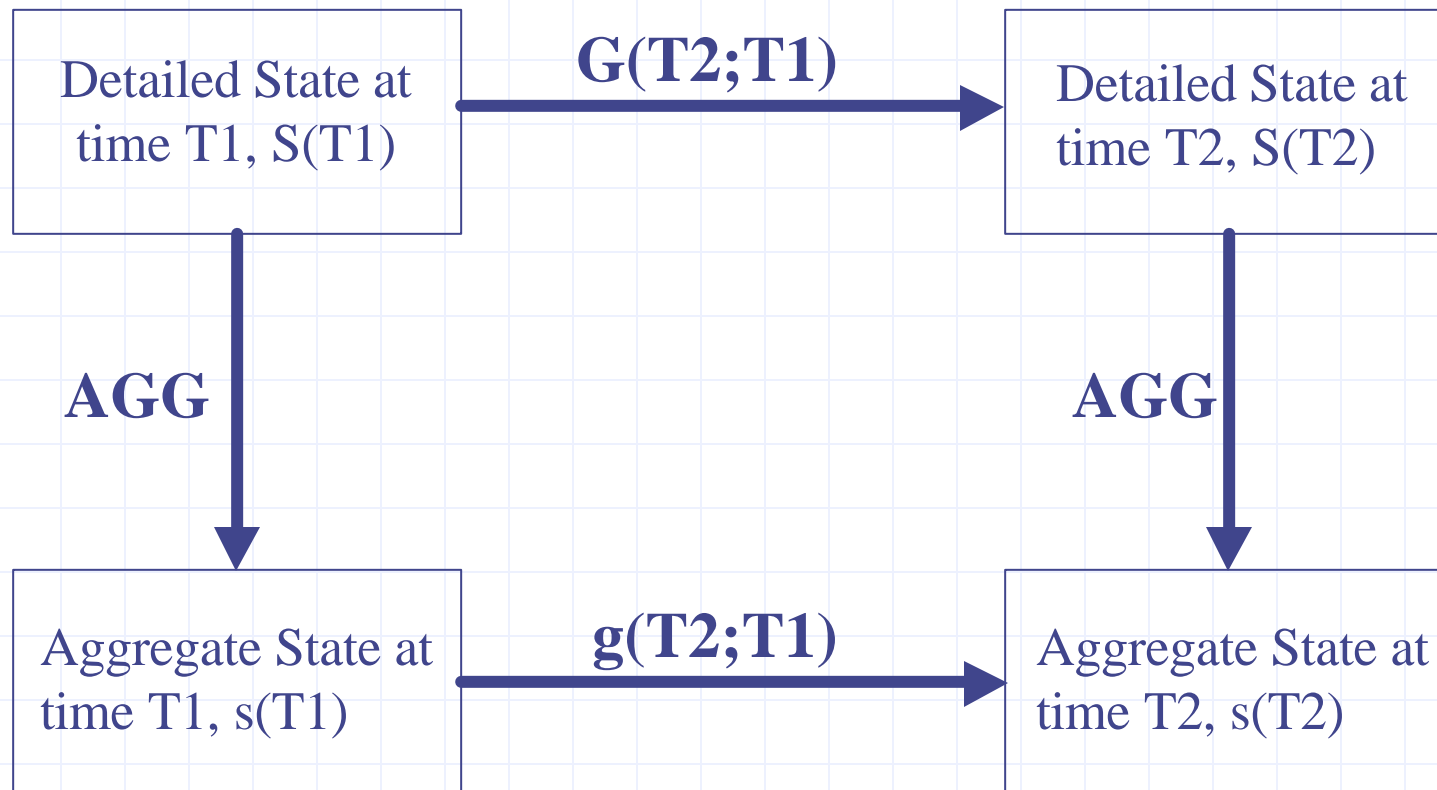
In modeling:

Our concern is whether an aggregated model is consistent with the high resolution model when simulating the same or similar scenario.

Two types:

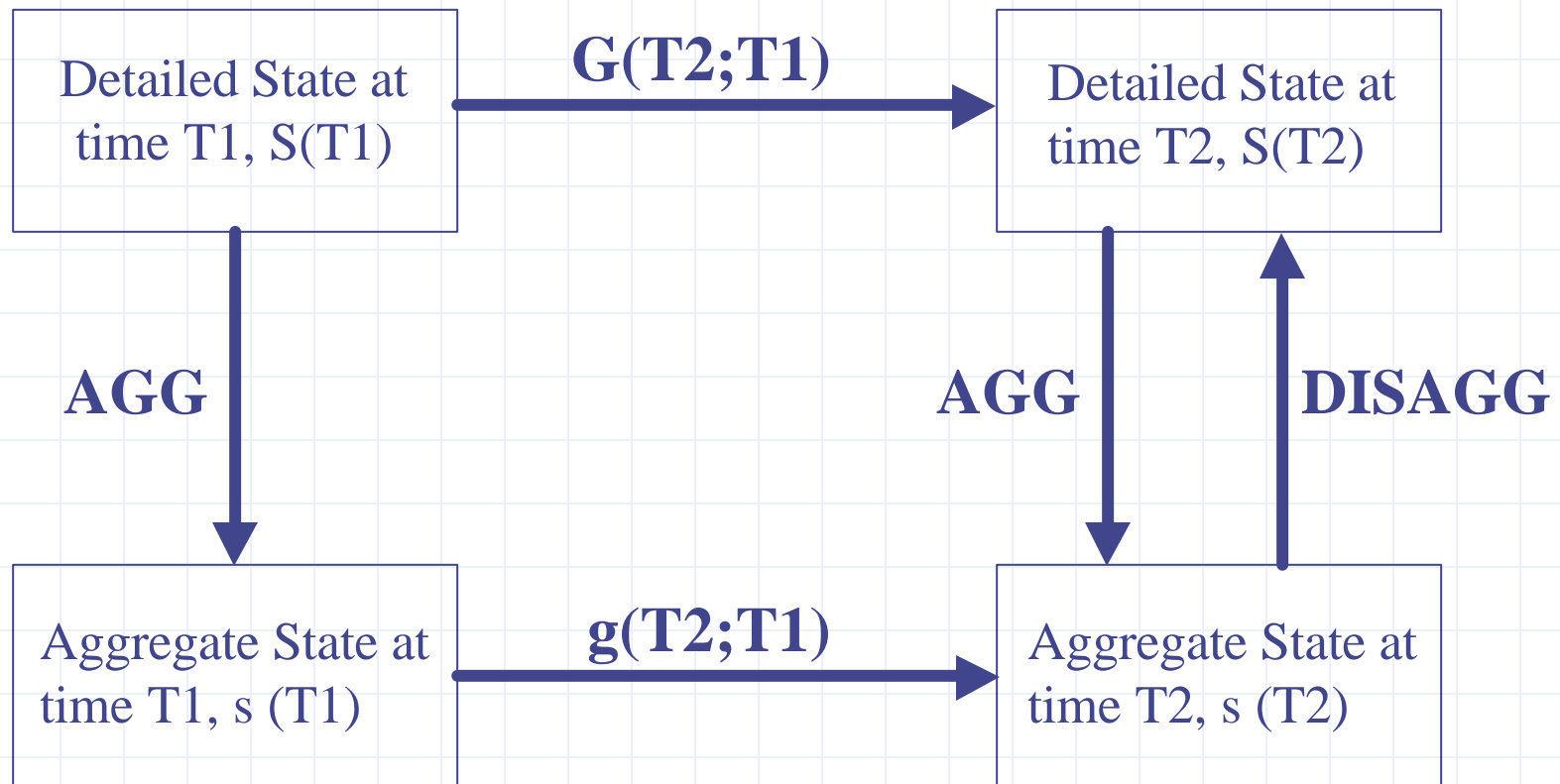
- Consistency in the Aggregate
- Complete Consistency

Definitions and Basic Concepts



Consistency in the Aggregate

Definitions and Basic Concepts



Complete Consistency



Importance of Variable Resolution Modeling

Importance of Variable Resolution Modeling

➤ **Need Low Resolution Modeling for....**

- Initial cuts
- Comprehension
- Systems Analysis
- Decision Support
- Adaptability
- Low Cost and Rapid Analysis
- Making use of Low Resolution Knowledge and Data

➤ **Need High Resolution Modeling for...**

- Understanding Phenomena
- Representing Knowledge
- Simulating Reality
- Calibrating and Informing Lower Resolution Models
- Making use of High Resolution Knowledge and Data

Importance of Variable Resolution Modeling

➤ Need for Variable Resolution Modeling...

- Provide a Picture
- Special Processes
- Establish Bounds
- Calibration
- Decision Support
- Adaptive Scenarios

The need is one thing...having it is another!

Importance of Variable Resolution Modeling

➤ Approaches to Variable Resolution Modeling:

- Selected Viewing
 - Carry along full resolution.
 - Display lesser resolution as appropriate.
- Alternative Submodels (Model Families)
 - Models have switches.
 - Submodels have different resolutions.
 - Submodels may or may not be integrated.
- Integrated Hierarchical Variable Resolution (IHVR)
 - Composed hierarchically of subordinate processes.



Example: Cross Resolution Model

Cross Resolution Model

➤ Cross Resolution Model

- Linking of existing models with different resolutions.
- A traditional approach, usually after-the-fact.

➤ Example from Rand VRM Workshop in 11/91.

- Two independently developed high/low resolution models for similar scenario.

➤ Goal:

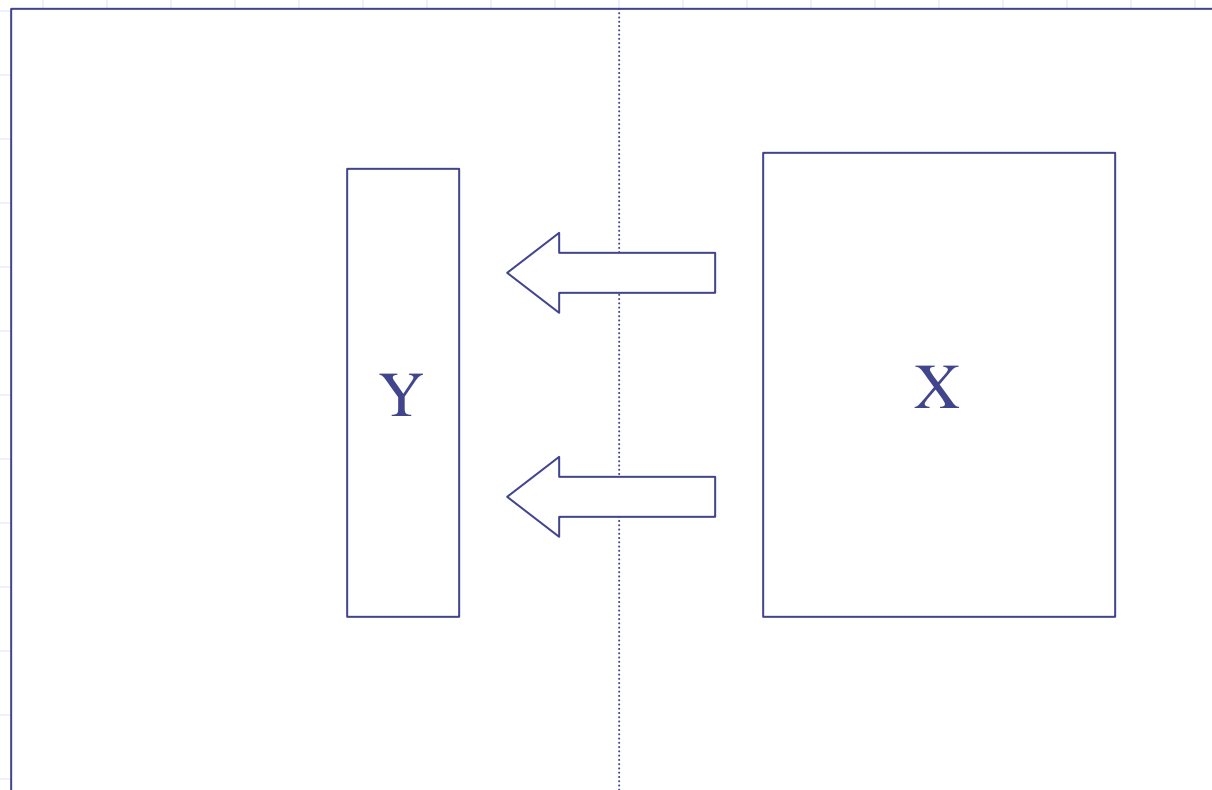
- Build a hierarchical model by using a higher resolution model to calibrate lower resolution model
- Appreciate the difficulties in this approach.
- Discover need for the Integrated Hierarchical Variable Resolution Approach.

Cross Resolution Model

➤ Modeling Scenario...

- Ground Combat with Attacker (X)/Defender (Y).
- Head on Head Attrition.
- Level: Army attacking Corps.
- Underlying Assumptions:
 - Forces Measured in Equivalent Divisions (ED's).
 - 3:1 Rule applies Fighting a Stalemate.
 - Governed by Lanchester "Square" Law.

Low Resolution Model



Low Resolution Model

➤ Inputs:

- X_0 : X (Attacker) Initial Force Size (ED's)
- Y_0 : Y (Defender) Initial Force Size (ED's)
- a : Attrition Coefficient (X killed per Y Firer Per Unit Time)
- b : Attrition Coefficient (Y killed per X Firer Per Unit Time)

➤ Variables of Interest:

- X : X (Attacker) Force Strength (ED's)
- Y : Y (Defender) Force Strength (ED's)
- F : Attacker/Defender Force Ratio (X/Y)
- XLR : X (Attacker) Loss Rate ($\Delta X/X$)
- YLR : Y (Defender) Loss Rate ($\Delta Y/Y$)
- RLR : Relative Loss Rate (XLR/YLR)

Low Resolution Model

➤ Applying General Model Assumptions:

- Lanchester "Square" Law Applies:

$$dX/dt = -aY$$

$$dY/dt = -bX$$

- 3:1 Rule...Fighting a Stalemate

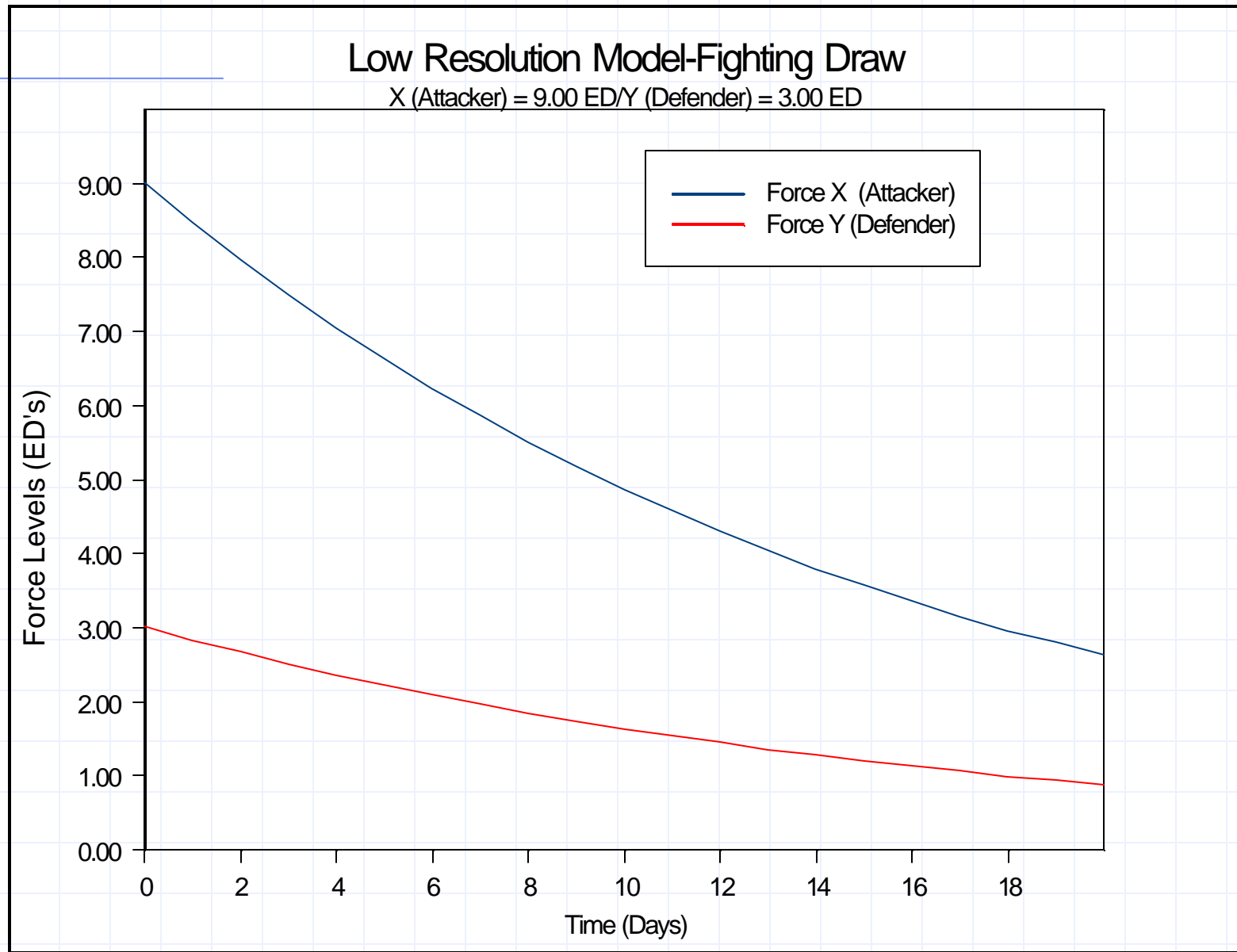
$$F \text{ (Force Ratio)} = 3 \quad \text{RLR} = 1$$

$$\text{RLR} = \frac{X_{LR}}{Y_{LR}} = \frac{dX/dt/X}{dY/dt/Y} = \frac{-aY/X}{-bX/Y} = \frac{a/b}{F^2}$$

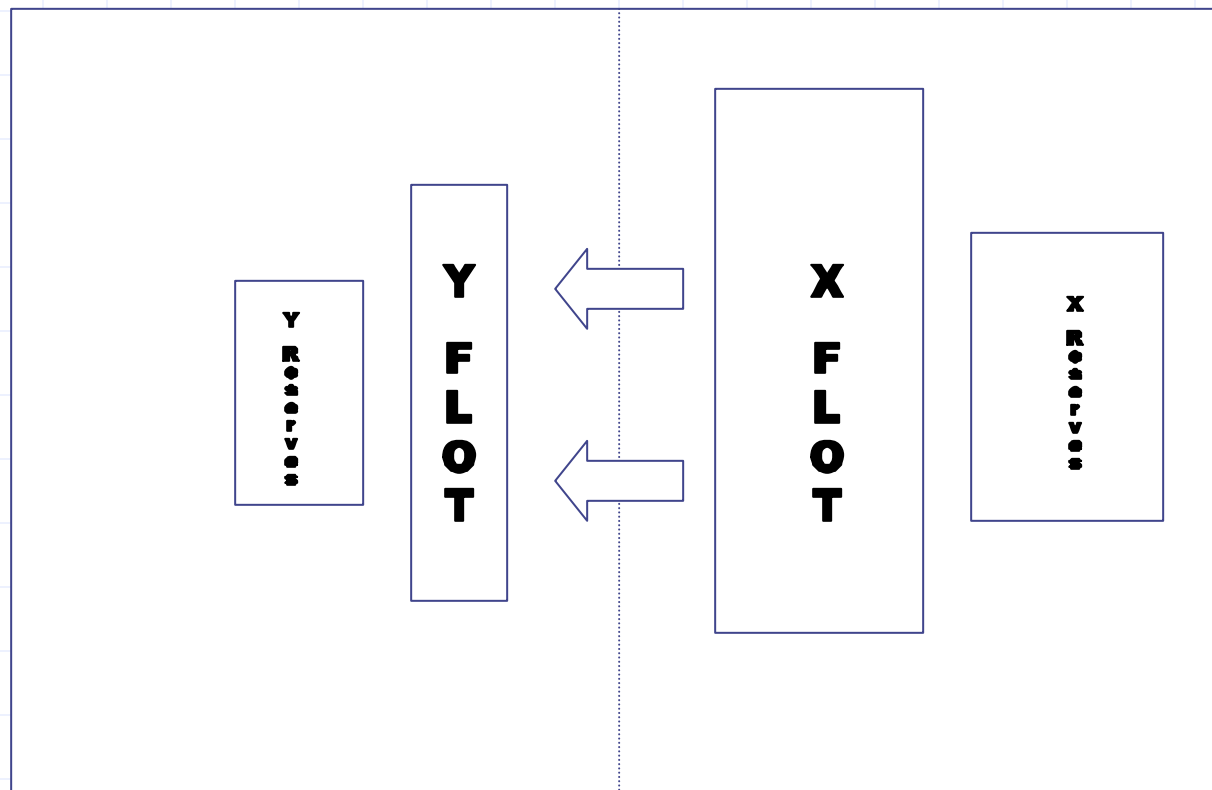
Implies that a/b (Defender Advantage) = 9

This model uses $a = .18$, $b = .02$.

Low Resolution Model



High Resolution Model



High Resolution Model

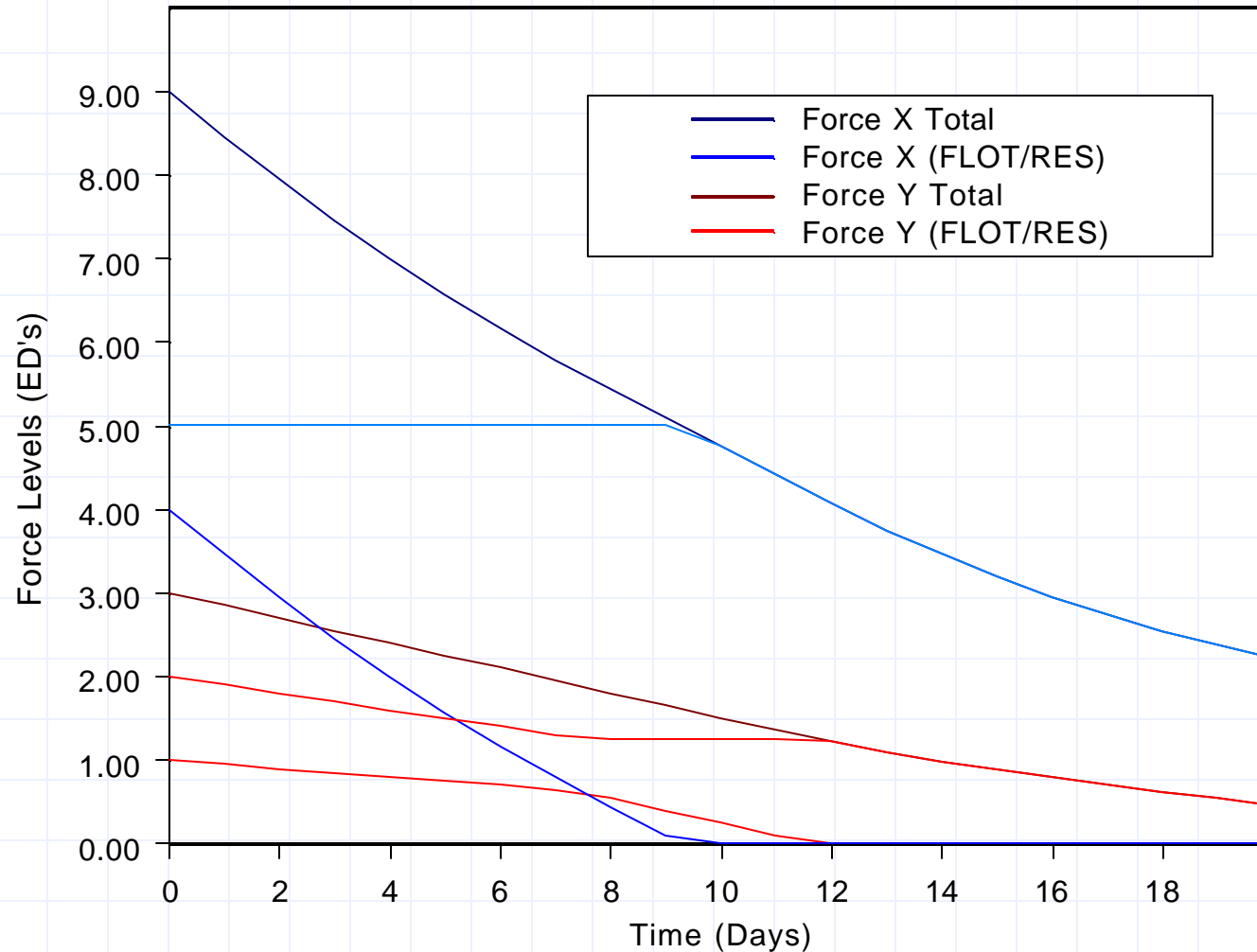
➤ Key Differences from Low Resolution Model:

- Incorporation of Reserves.
- Implementation of Shoulder Width Constraints.
 - X Strategy:
 - Place as many forces in FLOT up to minimum shoulder width constraint.
 - Y Strategy:
 - Never put more forces in FLOT than permitted by minimum shoulder width.
 - Maintain 2/3 forces on FLOT while no worse than maximum shoulder width.
 - Supplement larger fraction in FLOT when no longer able to maintain maximum.
 - Last resort place all forces in FLOT.

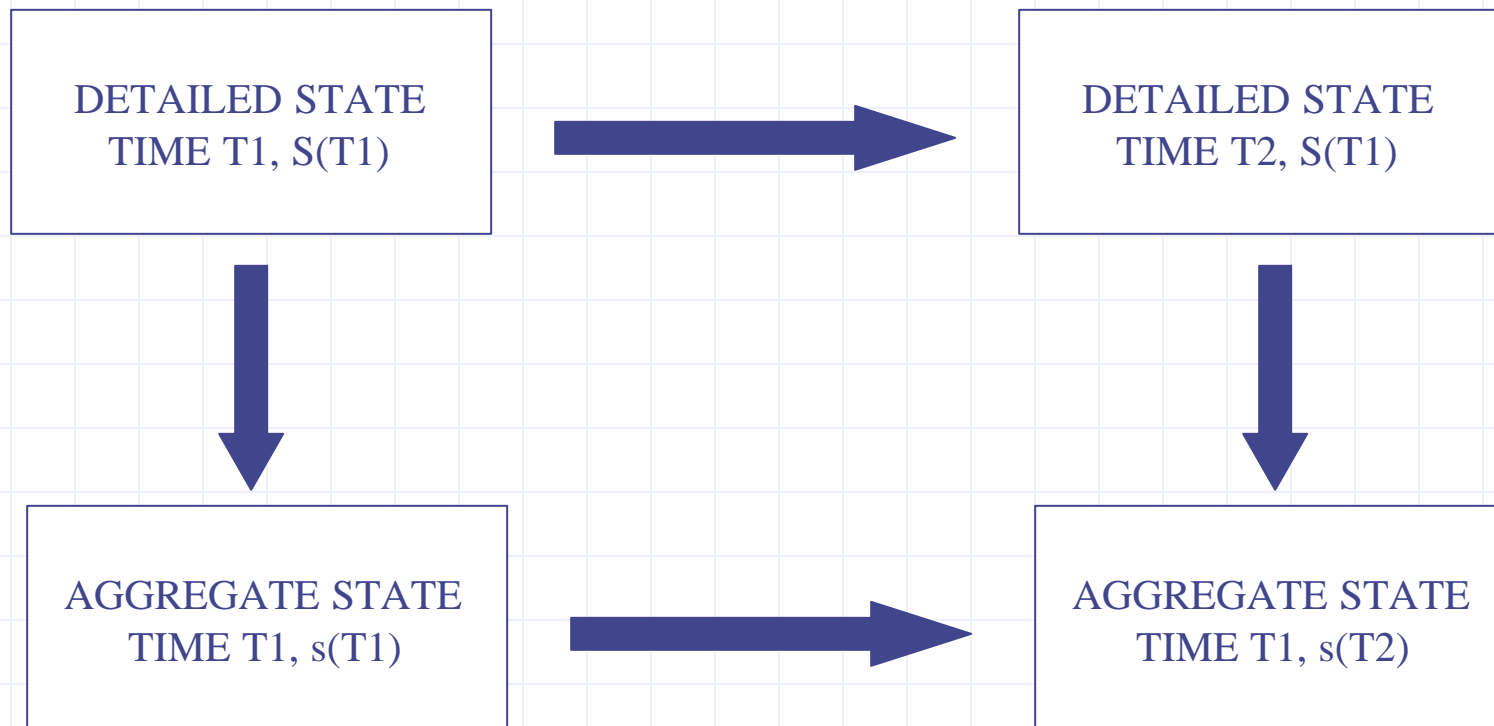
High Resolution Model

High Resolution Model-Fighting Draw

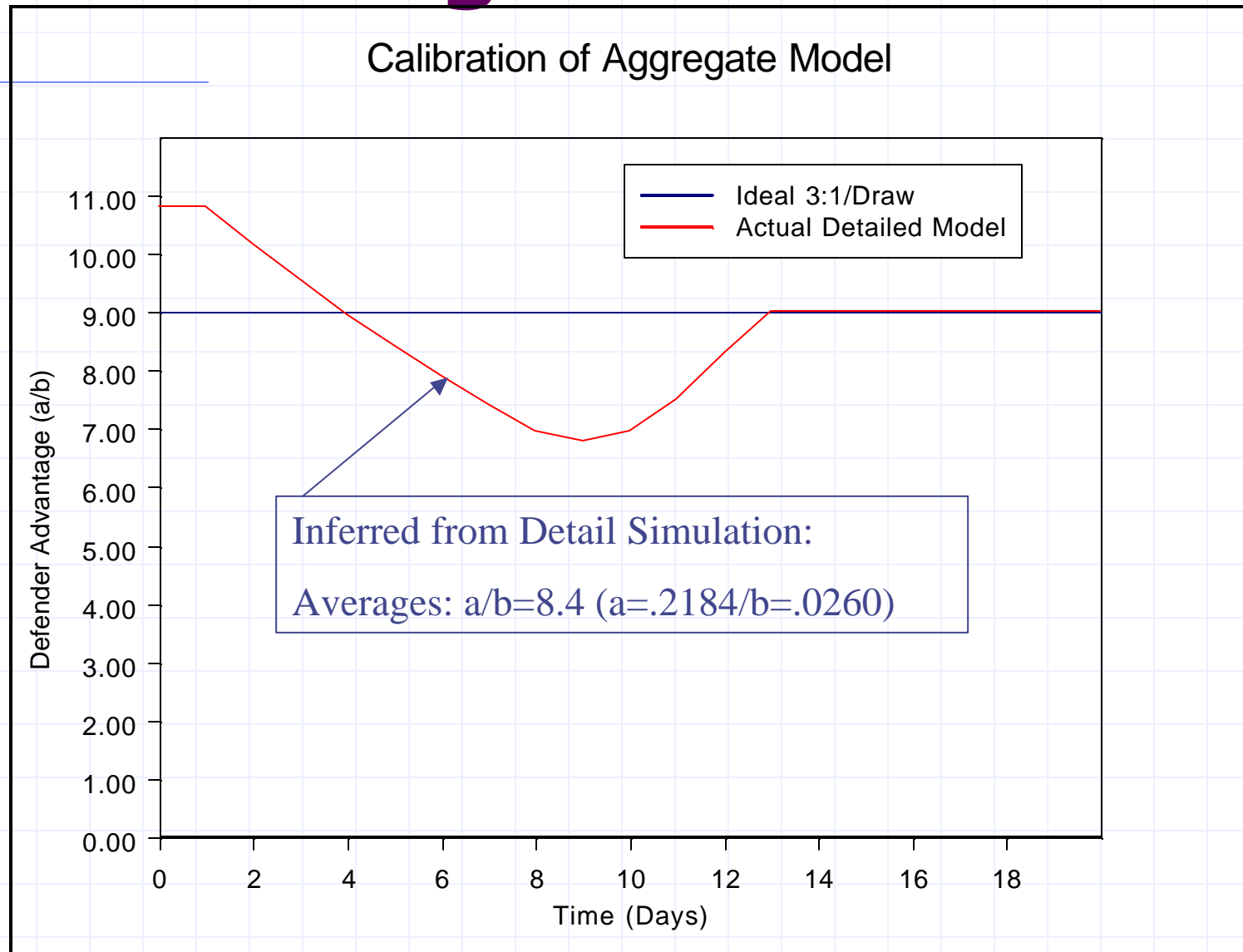
X (Attacker) = 9.00 ED/Y (Defender) = 3.00 ED



Goal...Consistency



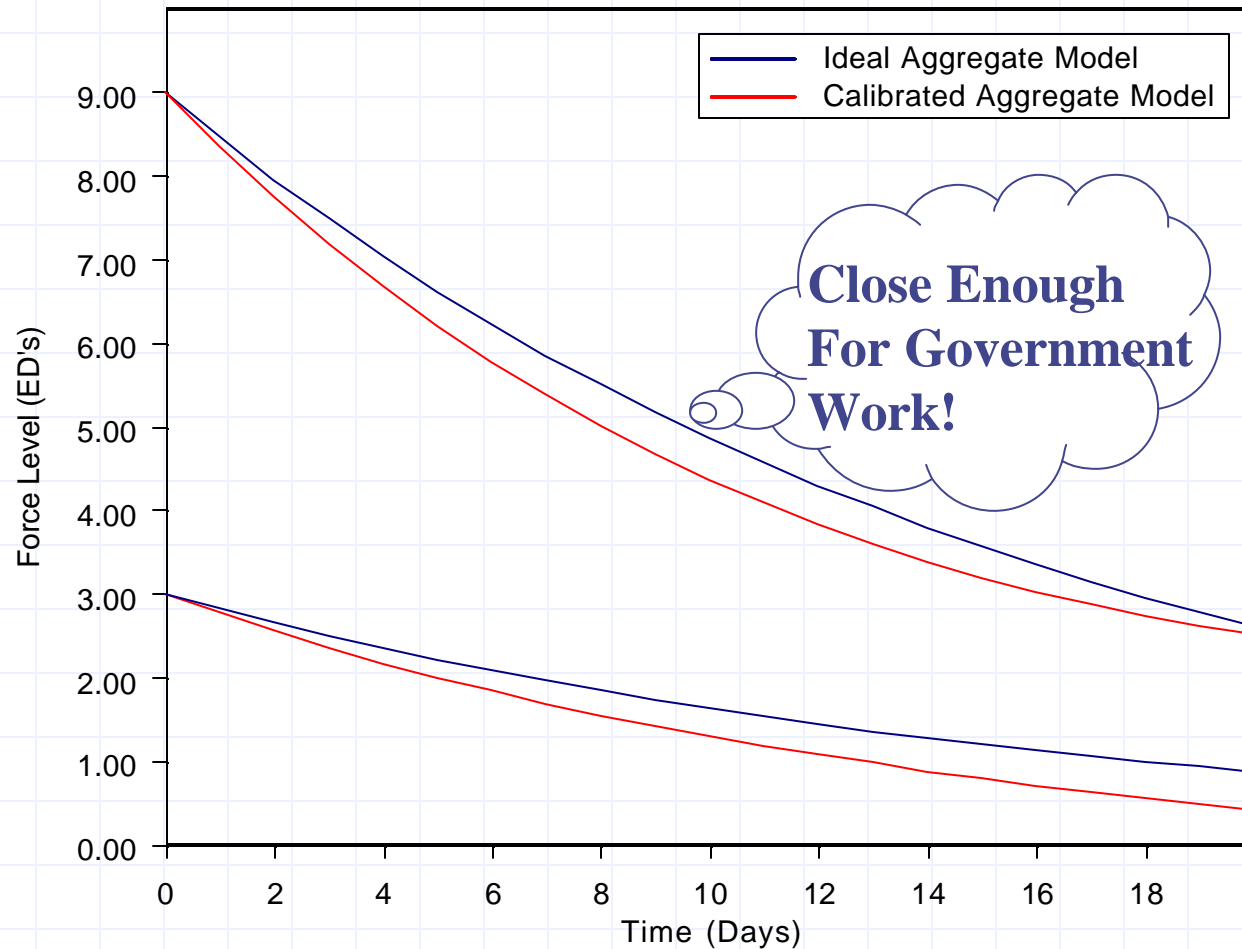
Calibrating the Models



Consistency???

Low Resolution Model

Ideal vs Calibrated Model



Consistency in the Aggregate!

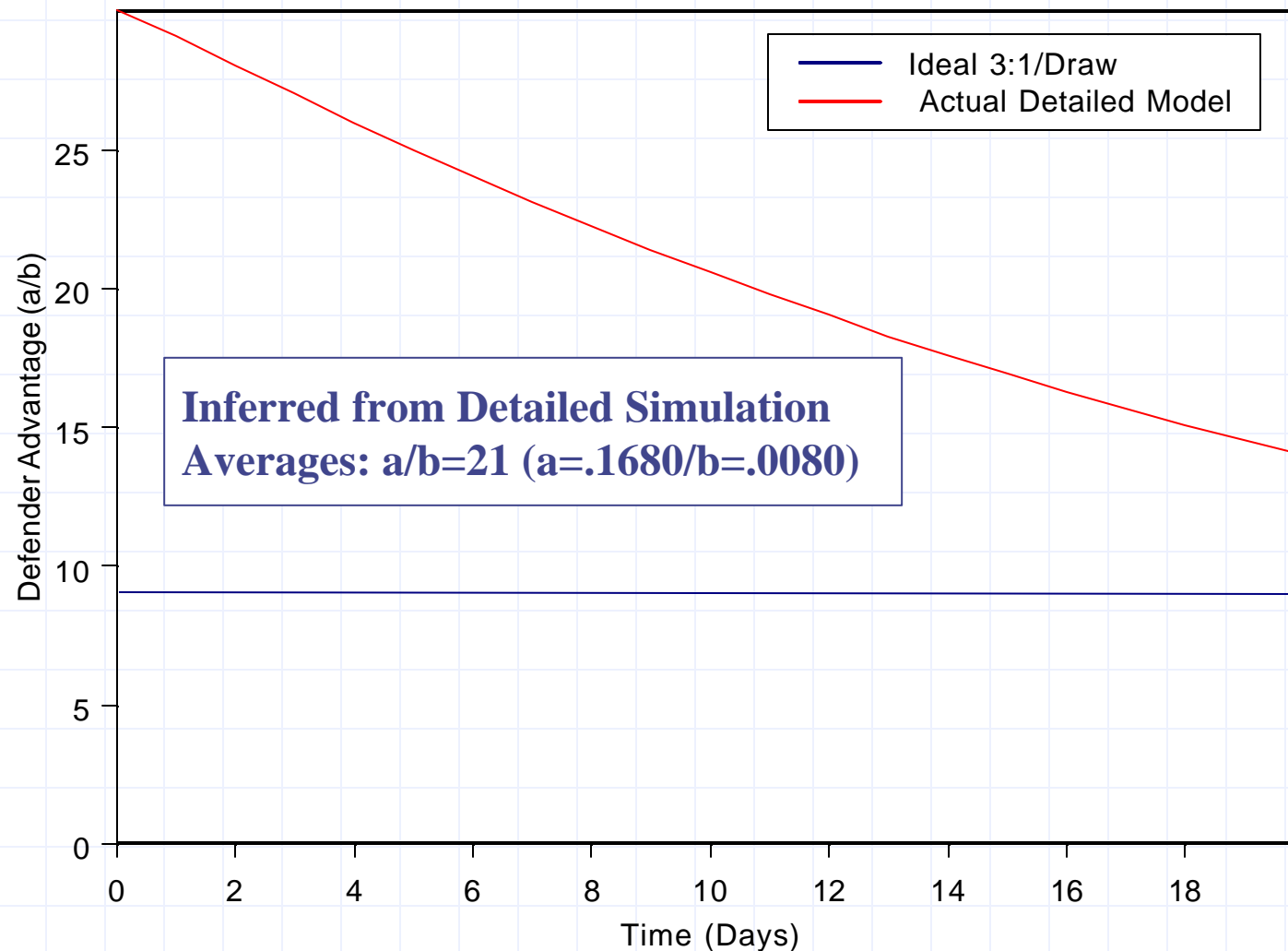
Sensitivity Testing

➤ *Lets try a different case...*

- Change only force sizes (X (Attacker)=25/ Y (Defender)=5).
- Battlefield and shoulder constraints remain constant.
- Use same calibration technique as before.

Calibrating the Models

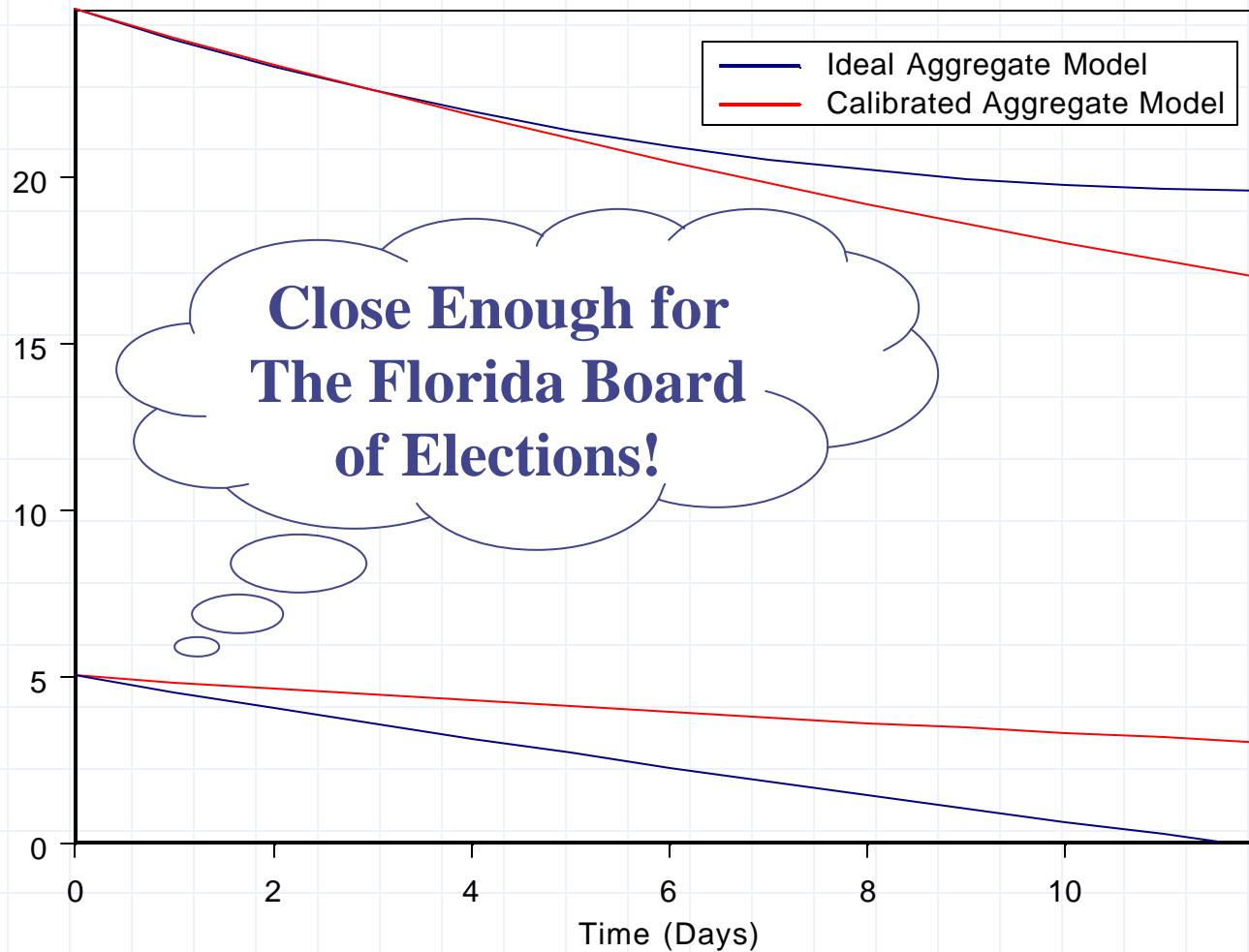
Calibration of Aggregate Model



Consistency???

Low Resolution Model

Ideal vs Calibrated Model



Inconsistent...

Breakdown in Model

- **Why???**

- Not fully understanding the model...the blackbox!
 - Reserve Implementation.
 - Shoulder Space Limits.
 - Result a fluctuating defender advantage ratio.


- **Possible Fixes???**

- Patching...equivalent to band aids on the models.
- Often poorly implemented and difficult to track.
- Not well documented or explained.

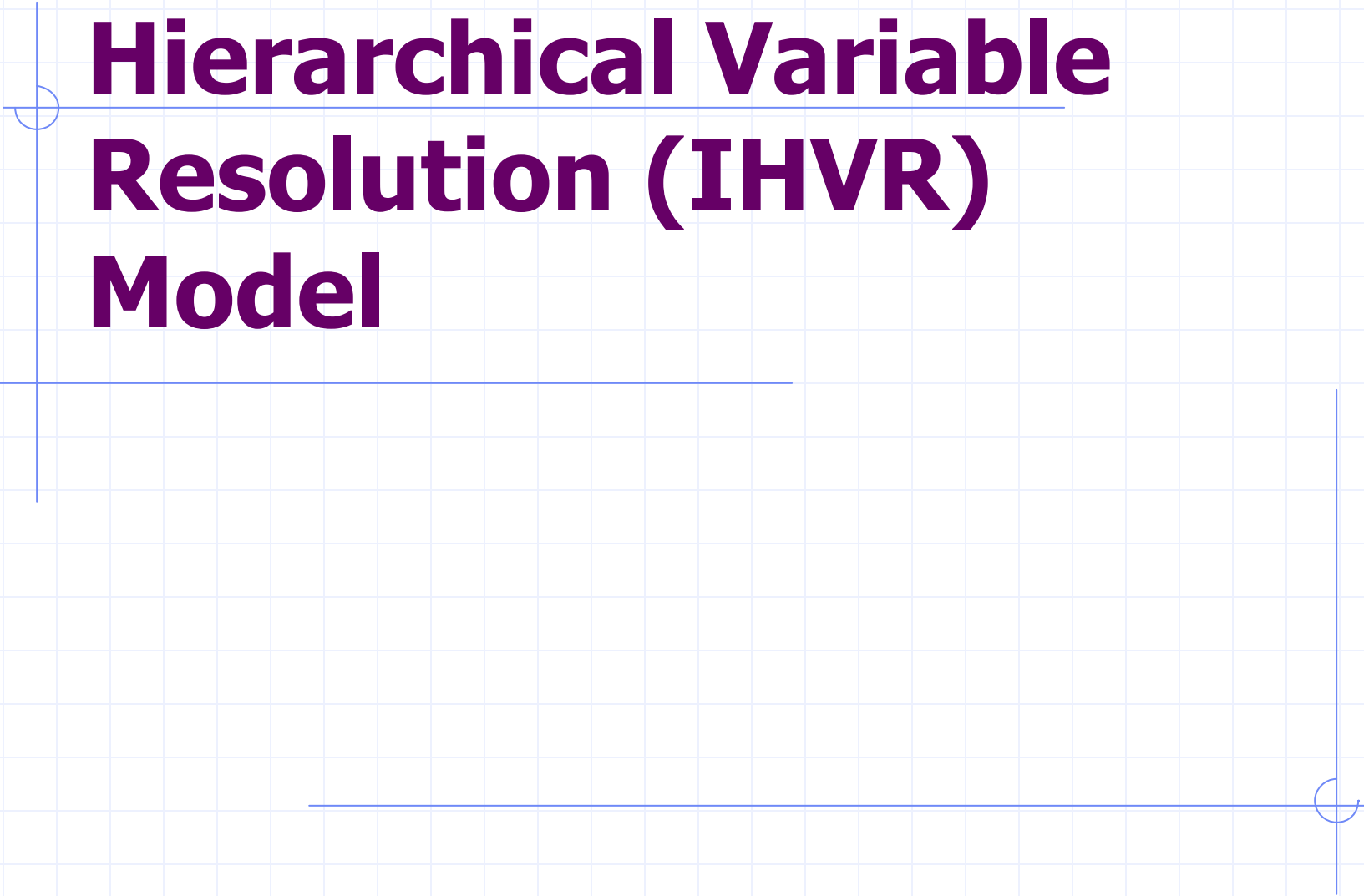
Breakdown in Model

- **Details not important...what is...**
 - Methodology such as this is common in modeling.
 - Not understanding models decision logic leads to breakdown.
 - Even the simplest of models can fail.

- **Result...**
 - Hierarchy can be painstakingly achieved...
 - Relationships NOT INTEGRATED NOR SEAMLESS...
 - CAN WE DO BETTER...



The Integrated Hierarchical Variable Resolution (IHVR) Model



IHVR Model

➤ **In the previous model we saw...**

- Models combined with incompatible and varied resolution.
- Attainment of hierarchy through calibration was:
 - In some cases, painful and imprecise.
 - In other cases, sound but painful.
 - Calibration is very sensitive to changes in model parameters.

➤ **The alternative approach...**

- Integrated Hierarchical Variable Resolution:
Model that describes critical processes as a hierarchy of subordinate processes.

IHVR Model



IHVR Model

➤ **Step 1: Develop a reference model.**

- Develop a complete data dictionary with consistent and intelligible notation.
- Contains all variables of original two models.
- May contain additional variables to complete the picture
- Names in reference model often different.

IHVR Model

➤ Applied to previous example...

X, Y	total force levels
$X_{\text{FLOT}}/Y_{\text{FLOT}}$	force levels in FLOT
a, b	attrition coefficients for total forces (aggregate)
$a_{\text{FLOT}}/b_{\text{FLOT}}$	attrition coefficients for FLOT forces
L_G/L	geographic and military usable frontage
$XDF_{\text{MIN}}/XDF_{\text{MAX}}$	minimum and maximum attacker frontages
$YDF_{\text{MIN}}/YDF_{\text{MAX}}$	minimum and maximum defender frontages
terr, type battle	correction factor parameters to account for terrain and battle circumstances
$X_{\text{BP}}/Y_{\text{BP}}$	force breakpoints

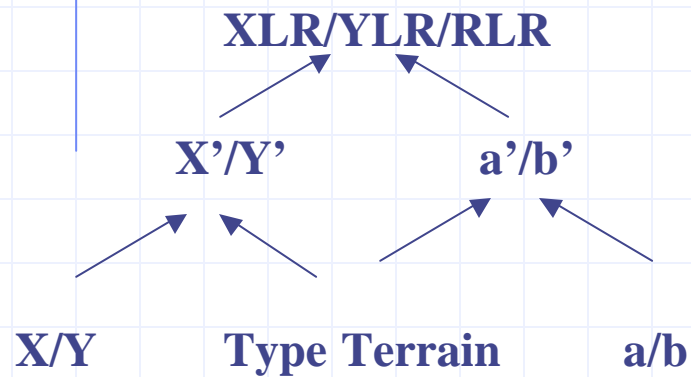
IHVR Model

- **Step 2: Draw pictures showing functional relationships.**
 - Skeletons/flow-charts for data flow in model.
 - Attempt to fit a hierarchical structure.
 - Greatly enhances computer implementation.

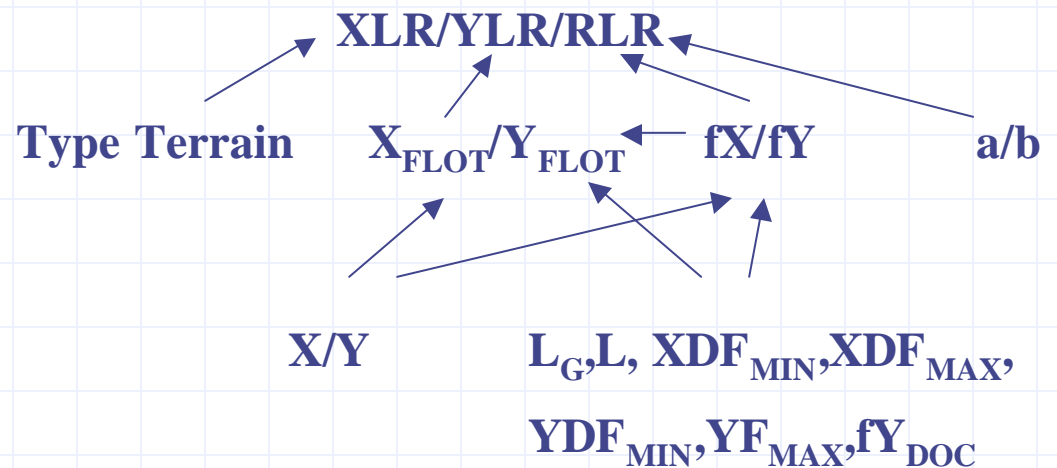
IHVR Model

➤ Applied to previous example...

Low Resolution Model



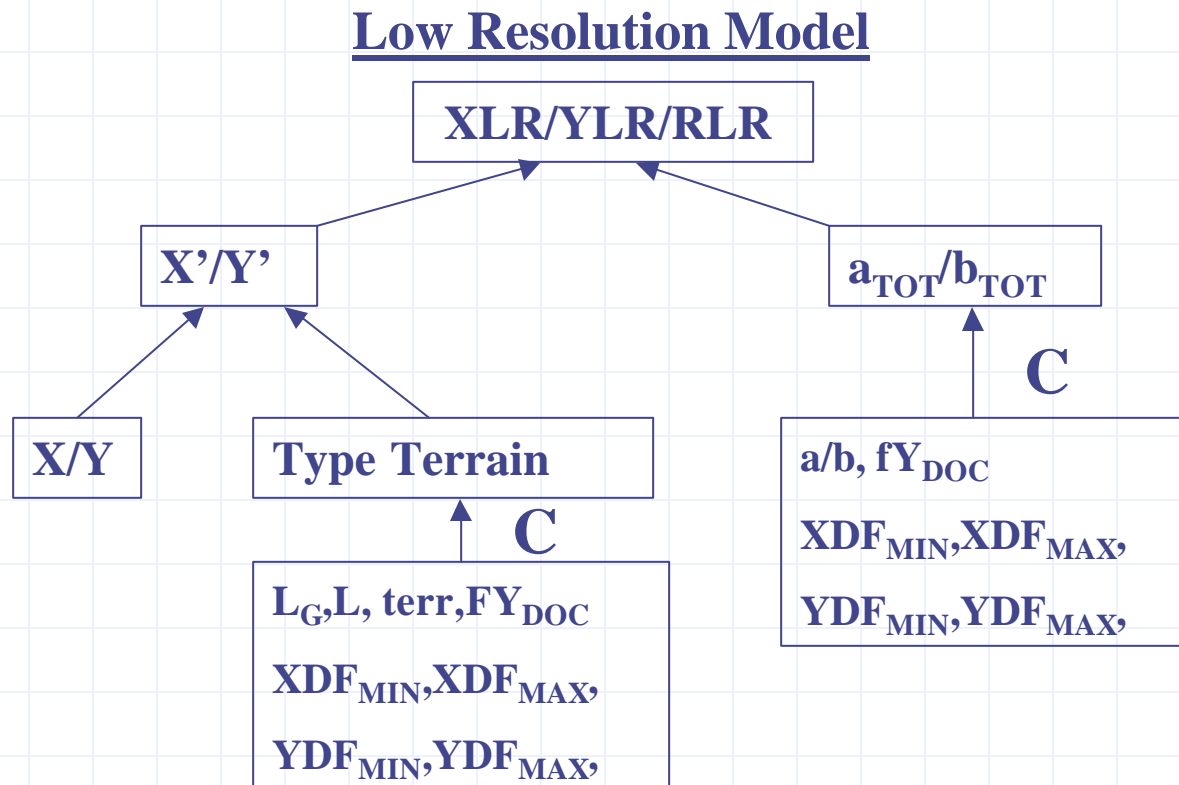
High Resolution Model



Before... Definitely not hierarchical design...

IHVR Model

➤ Applied to previous example...

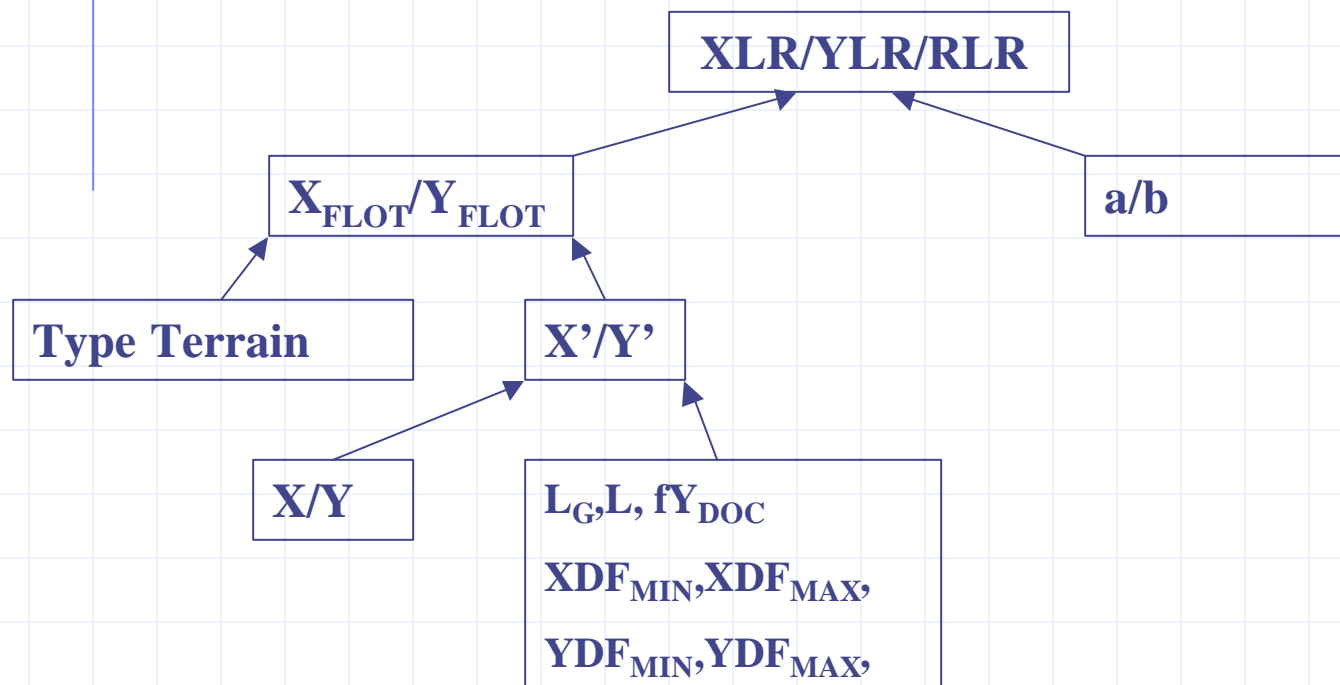


After... More hierarchical design...

IHVR Model

➤ Applied to previous example...

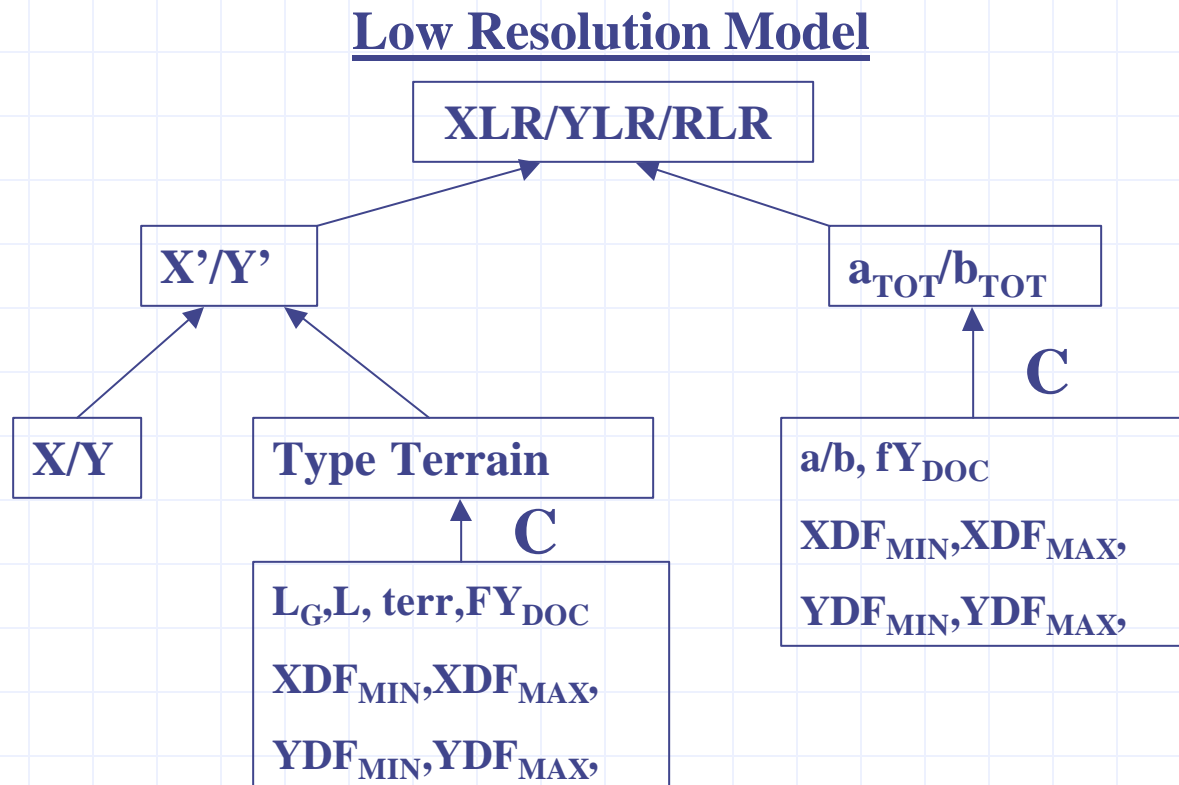
High Resolution Model



After... More hierarchical design...

IHVR Model

➤ Applied to previous example...



After... More hierarchical design...



Challenges of Variable Resolution Modeling

Challenges of Variable Resolution Modeling

➤ Generic Challenges of Variable Resolution Modeling...

- Getting concepts and names straight.
- Completing sets of variables and functions.
- Deciding form of reasonable aggregate equations relative to detailed equations.
- Finding conditions under which equations might be reasonability valid.
- Expressing aggregate model parameters in terms of outputs of detailed model.
- Deciding on cases to be distinguished and how to make calibrations for each case.

Challenges of Variable Resolution Modeling

➤ Recommended Approach to Design...

- Develop initial design focusing on composition and top-down views.
- Anticipate need for variable resolution.
- Make choices of perspective to determine “best” hierarchical structures.
- Use rapid prototyping...Focus on inputs and outputs...Use theory to tighten calibration relationships.
- Experiment and iterate.
- Complete top-level design and proceed.
- Do not lightly assume “simple” aggregation relationships.
- Adapt with applications, but don’t undercut design.



Summary

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- *Reviewed Definitions and Basic Concepts*
- *Discussed the Importance of Variable Resolution Modeling*
- *Example*
 - Cross Resolution Model
 - Integrated Variable Resolution Model
- *Challenges of Variable Resolution Modeling*



Our Questions???

Our Questions???

➤ **Define Variable Resolution Modeling.**

Building models or model families so that users can readily change the level of detail at which phenomena are treated

➤ **Why Might One Desire Variable Resolution Modeling?**

- Provide a picture.
- For special processes.
- Establish bounds.
- Calibrate other models.
- Decision support.
- Generate adaptive scenarios.

Our Questions???

- **Name 3 Approaches to Variable Resolution Modeling.**
 - Selected Viewing.
 - Alternative Submodels (Model Families).
 - Integrated Hierarchical Variable Resolution (IHVR).
- **(T/F) Calibration of a lower resolution model using a higher resolution model guarantees consistency.**
 - False.



Your Questions???